**Refraction of Light Summary Sheet**

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| **Refraction, Index of Refraction, Snells Law, Total Internal Reflection** | |
| **Index of Refraction**: The index of refraction n of a material is the ratio of the speed *c* of light in a vacuum to the speed *v* in the material | 1. Always greater than one 2. Water = 1.333 3. Glass, crown = 1.523 4. Quartz, crystalline = 1.544 5. Quartz, fused = 1.458 |
| **Snells Law of Refraction:** When light travels from a material with refractive index n1 into a material with refractive index n2, the refracted ray, the incident ray, and the normal to the interface between the materials all lie in the same plane. The angle of refraction θ2 is related to the angle of incidence θ1 by | When a ray of light is directed from air into water, part of the light is reflected at the interface and the remainder is refracted into the water. The refracted ray is bent ***toward*** the normal (θ2 < θ1).  When a ray of light is directed from water into air, the refracted ray in air is bent ***away*** from the normal(θ2 > θ1). |
| **Total Internal Reflection**   * Can happen when light passes from a medium of larger refractive index into one of smaller refractive index * When the angle of incidence reaches a certain value – called the **critical angle θc**, the angle of refraction is 90°. * In this case, there is no refracted light, all light is reflected back into the material * Critical Angle:   (n1 > n2)   * This is how a fiber optic cable transmits light without significant losses in intensity. | 1. When light travels from a higher-index medium (water) into a lower-index medium (air), the refracted ray is bent away from the normal.  1. When the angle of incidence is equal to the critical angle θc, the angle of refraction is 90°. 2. If θ1 if greater than θc, there is no refracted ray, and total internal reflection occurs. |

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| **Lenses** | |
| 1. Lenses are used in optical instruments such as eyeglasses, cameras, microscopes, and telescopes 2. Lenses are made from materials that refract light. 3. Two kinds of lenses:    1. Converging Lens       * Can form a real or virtual image    2. Diverging Lens       * Always forms a virtual image |  |
| **Ray Tracing for Converging and Diverging Lenses** | |
| **Converging Lens**  **Ray 1:** Initially parallel to the principal axis. In passing through the converging lens, the ray is refracted toward the axis and travels through the focal point on the right side of the lens. (a)  **Ray 2**: This ray passes through the focal point on the left and then is refracted by the lens in such a way that it leaves traveling parallel to the axis. (b)  **Ray 3**: This ray travels directly through the center of the thin lens without significant bending. (c) | **Diverging Lens**  **Ray 1:** Initially parallel to the principal axis. In passing through the diverging lens, the ray is refracted away from the axis and appears to have originated from the focal point on the other side of the lens. (d)  **Ray 2**: This ray leaves the object and moves toward the focal point on the right side of the lens. Before reaching the focal point, the ray is refracted parallel to the axis. (e)  **Ray 3**: This ray travels directly through the center of the thin lens without significant bending. (f) |
| **Thin Lens Equation and Magnification** | |
| **d0 = distance to object hi = Image height**  **di = distance to image ho = Object height**  **f = focal length**  **m = magnification** (+) for upright image  (-) for inverted image | **Focal length**  f is (+) for a converging  f is (-) for a diverging  **Object Distance**  do is + if the object is to the left of the lens (normal)  do is - if the object is to the right of the lens(rare)  **Image Distance**  di is + if the image is formed to the right (real image)  di is - if the image is formed to the left (virtual image) |

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| **Converging Mirror Object Positions** | |
| **Object is placed at the left of the point labeled 2F (twice the focal length)**   * **Image smaller in size** * **Real image** * **Image Inverted** |  |
| **Object is placed between 2F and F**   * **Image Larger in size** * **Real image**  * **Image Inverted** |  |
| **Object placed within the focal point F of the lens**   * **Virtual image**  * **Image Enlarged** * **Image Upright** |  |
| **Diverging Mirror Object Positions** | |
| **A diverging lens always creates a**   * **Virtual image**  * **Image smaller** * **Image *Upright*** |  |